§21. Ion Friction Forces on Dust Particle in SOL/Divertor Plasma

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The dominant force on a dust particle in SOL / divertor plasma is the ion friction forces. In this study the friction forces are studied. One of them is the friction force due to ion absorption and another is one due to the Coulomb scattering force of ions. They are expressed by the form:

$$\vec{F}_{iab/isc} = \pi R_d^2\, n_i\, T_i \frac{\vec{V}_i - \vec{\upsilon}_d}{\left|\vec{V}_i - \vec{\upsilon}_d\right|} \eta_{iab/isc}(u, T_i / T_e)\,. \qquad (1)$$

Here the subscripts *iab* and *isc* indicate the absorption and scattering forces, respectively. The quantities R_d, n_i, T_i, T_e, V_i, υ_d are the dust radius, ion density, ion temperature, electron temperature, ion flow speed and dust velocity, respectively. The quantity u is the normalized relative speed by the ion thermal speed $u \equiv \left|\vec{V}_i - \vec{\upsilon}_d\right| / \sqrt{2T_i / m_i}$. The coefficients $\eta_{ab/sc}$ are expressed by the normalized relative speed u and the plasma temperature ratio T_i/T_e [1,2].

$$\eta_{iab}(u, T_i / T_e) = \frac{1}{\sqrt{\pi} u^2}\{u(2u^2 + 1 + 2\chi_i)e^{-u^2}$$

$$+[4u^4 + 4u^2 - 1 - 2(1 - 2u^2)\chi_i]\frac{\sqrt{\pi}}{2}\mathrm{erf}(u)\} \qquad (2)$$

$$\eta_{isc}(u, T_i / T_e) = 4\chi_i^2 \ln\Lambda \frac{\mathrm{erf}(u) - 2u\exp(-u^2)/\sqrt{\pi}}{2u^2} \qquad (3)$$

$$\chi_i = Z_i Z_d e^2 / 4\pi\varepsilon_0 R_d T_i \qquad (4)$$

The quantities η_{iab}, η_{isc} and χ_i are the functions of the normalized relative speed u and the temperature ratio. In Fig. 1 the quantities η are shown as a function of the relative speed u for the case of $T_i / T_e = 1.0$. For the lower relative speed ($u < 1.0$) The difference between the quantities η_{iab} and η_{isc} is small. Fig.2 shows the quantities η as a function of the plasma temperature ratio for the case of relative speed u =0.1.

These friction forces can be compared to the intrinsic gravity of the dust particle.

$$\frac{F_{iab} + F_{isc}}{F_g} = \frac{3n_i T_i}{4g\rho_d R_d}[\eta_{iab}(u, T_i / T_e) + \eta_{isc}(u, T_i / T_e)]$$

$$= 1.23 \times 10^{-17} \frac{n_i T_{i,eV}}{\rho_{d,g/cc} R_{d,\mu m}}[\eta_{iab}(u, T_i / T_e) + \eta_{isc}(u, T_i / T_e)] \qquad (5)$$

For the larger dust particle than the critical radius $R_{d,mm,g}$, the gravity is larger than the friction forces:

$$R_{d,\mu m} \geq R_{d,\mu m,g} \equiv 1.23 \times 10^{-17} \frac{n_i T_{i,eV}}{\rho_{d,g/cc}} [\eta_{iab}(u, T_i / T_e) + \eta_{isc}(u, T_i / T_e)]$$

For the case of the carbon dust in the plasma pressure n_i T_i $=10^{19}$ m^{-3} eV with u = 1.0, the critical radius $R_{d,mm,g}$ is as large as 1.2 μm.

Other mechanisms, the thermionic current, secondary electron emission current and charging current due to impurities, have to take into account in the dust charging as well as the effects of magnetic field. The three-dimensional analysis and the dynamics near plasma-facing wall of the dust particle are left as future issues. These results might be useful to analyze the dust particle in SOL/divertor plasma of fusion devices.

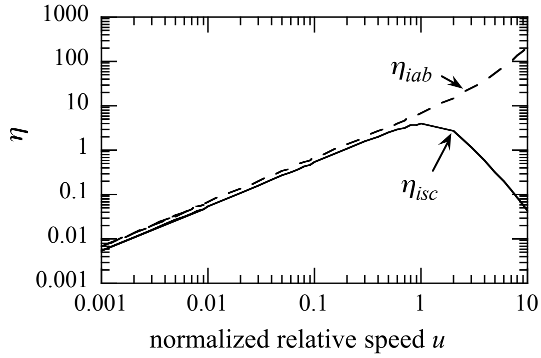

Fig.1 The coefficients η of the friction forces (the force due to Coulomb scattering of plasma ions: solid line, the force due to absorption of plasma ions: dashed line) as a function of the normalized relative speed, where $T_i / T_e = 1.0$.

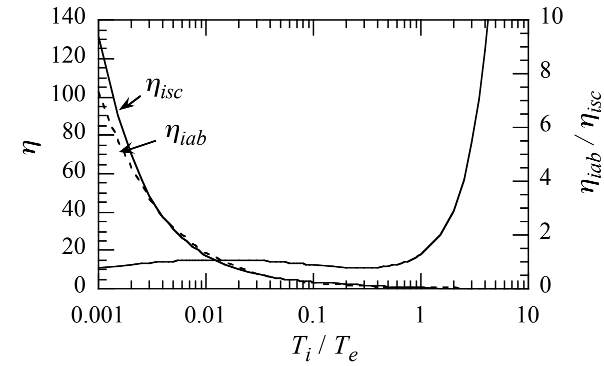

Fig.2 The coefficients η and their ratio as a function of the plasma temperature ration, where the normalized relative speed = 0.1.

1) Pigarov A., Krasheninnikov S., Soboleva T., Rognlien T., Phys. Plasma, **12**, 122508 (2005).
2) Smirnov R D, Pigarov A Yu, Rosenberg M, *et al.*, Plasma Phys. Control. Fusion, **49**, 347 (2007).